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THE BBN-LISP SYSTEM

Daniel G. Bobrow
D. Lucille Darley
Daniel L. Murphy
Cynthia Solomon
Warren Teitelman

Bolt Beranek and Newman Inc.
50 Moulton Street
Cambridge, Massachusetts 02138

February, 1966

Prepared for:

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OFFICE OF AEROSPACE RESEARCH
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FOREWORD

The work reported here was performed at Bolt Beranek and
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THE BBN-LISP SYSTEM

ABSTRACT

This report describes in detail the BBN-LISP system. This
LISP system has a number of unique features; most notably,
it has a small core memory, and utilizes a drum for storage
of list structure. The paging techniques described here
allow utilization of this large, but slow, drum memory with
a surprisingly small time penalty. These techniques are
applicable to the design of efficient list processing systems
embedded in time-sharing systems using paging for memory
allocation.

SECTION I.

INTRODUCTION

LISP is a highly sophisticated list-processing language which
is being used extensively in the artificial intelligence re-
search program at Bolt Beranek and Newman. This report
describes our LISP system, which has a number of unique
features. Ideally, a LISP system would have a very large,
fast, random-access memory. However, magnetic core memory
(the only large scale random-access memory available) is
very expensive relative to serial memory devices such as
magnetic drums or discs. Since average access time to a
word on a drum or disc is approximately 1000 times slower
than access to a word in a core memory, using a drum as a
simple extension of core memory would reduce the operating
speed of a system by a factor of 1000.

We have developed a special paging technique which allows
utilization of a drum for storage with a much smaller time
penalty. This technique allows us to make effective use of
a LISP system on our PDP-1 which has only 8392 18-bit words
of 5 microsecond core memory and 92,312 words on a drum
with an average access time of 16.5 milliseconds. In addi-
tion, the techniques reported here would improve the speed
of operation of LISP systems embedded in time-sharing
systems using paging for memory allocation. In these time-
sharing systems the user is allocated only a small portion
of core memory at any time, although his program can address
a large virtual memory. The portion of his data structure
and/or program not in core is kept in a slower secondary

storage medium such as a drum or disc. Thus, to the user it is very similar to the situation on our PDP-1, except that a hardware mechanism makes the program transparent to the medium of storage of any page of his program.

Section II of this report describes the internal structure of the BBN-LISP system, and the mechanisms used to facilitate fast use of drum storage. Section III describes the LISP functions which are built into the basic system. Section IV contains listings of those functions which are defined in LISP.

Although we have tried to be as clear and complete as possible, this document is not designed to be an introduction to LISP. Therefore some parts may be clear only to people who have had some experience with other LISP systems.

THE INTERNAL STRUCTURE OF
THE BBN-LISP SYSTEM

The BBN-LISP System uses only a small core memory, but achieves
a large memory capacity by utilizing a drum. This drum is
used in three ways. First, the working program is divided into
three overlays, the read and print (input-output) program, the
garbage collector, and the interpreter of S-expressions. Only
one of these overlays is in core at any time, although a number
of sub-programs common to all three remain in core at all times.

Secondly, the drum contains a large push-down list for use in
running recursive programs. This push-down list is double-
buffered; that is, the section of the push-down list used most
recently is in core and the section used immediately preceding
this section is also there, so that traveling between buffers
does not necessitate a drum reference.

The third way of utilizing this large secondary store, the drum,
is for storage of list structure. If the entire remaining drum
storage was used simply as an extension of core memory, an
access to the drum would be needed each time a new list element
was referenced; and LISP would be reduced to operating at drum
rotation speed. Instead, the drum storage of list structure is
divided into pages. Each page is currently 258 words (decimal);
and each page contains its own free storage list. The cons
algorithm, for constructing a new list element, works as follows.

To construct z = cons [x;y]:

> 1) If y is not an atom, and there is room on the page
> with y, then place z on this page
>
> 2) Otherwise, if x is not an atom, and there is room
> on the page with x, put z on that page
>
> 3) Otherwise, place z on the page in core with maximum
> free storage.

This algorithm tends to minimize cross linkages between pages
and to limit any single structure to a very few pages. Thus
when working with this structure, it is unlikely that one will
make references to more than a few pages for a relatively long
period of time. Since these pages can reside in core, no drum
references are needed. For example, in entering the definition
of a function, the entire definition tends to appear on a single
page. Thus, during the interpretation of a function, multiple
drum references are usually unnecessary.

Although we have not yet run this LISP system on a large problem
where we can make a reasonable timing comparison, we can give
the following anecdotal evidence for the increase in speed due
to this paging system. The run light on the PDP-1 goes off when
a drum swap is taking place. In an older version of PDP-1 LISP
the drum was treated as an extension of core memory. When any
problem was run, the run light seemed to go off completely, in-
dicating that the machine was spending almost all of its time
doing drum transfers. In this system, however, the run light
seems to burn as brightly as the rest, indicating that relatively
few drum transfer operations occur except when going between the
three overlay packages, that is, when going from input and out-
put back to the interpreter or going into a garbage collection.

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On the research computer, because of the drum storage, we currently have in use an effective free storage list of approximately 25,000 LISP words, i.e., double word pairs (pointers). Each LISP word is, of course, two 18-bit PDP-1 words. In the extended version of LISP that will be used on the hospital system we will have 256,000 LISP words for free storage.

There are a number of differences between this system and 7094 LISP aside from the storage conventions. For example, the value of a variable is stored in a special value cell for that variable, that is, as car of the atom name. An atom is distinguished by its address, which is located in a fixed region of virtual memory space. Thus one need not reference a structure, but only look at its address, in order to tell whether or not it is an atom. If x is an atom, then $cdr[x]$ is the property list of the atom, as in 7094 LISP. However, the print name of the atom is not to be found on this property list. The user can only get at the print name with the instructions pack and unpack. Similarly, the definition of an atom as a function is hidden away from the user in a special cell associated with the atom name. Two functions, $getd[x]$ and $putd[x;def]$ are used to get the definition of a function, and place the definition in the function cell of an atom, respectively. The value of $getd[x]$ on an atom defined as a machine language subroutine is a numerical constant which bears some relationship to the instruction that must be executed to obtain access to the subroutine.

When a new function is entered, the old values of its variables are pushed down on the push-down list, and the current values are stored in the value cells. Since the current value of any

variable is always to be found in its value cell, free variables are no problem. However, there is the usual anomalous case of conflicting free variables in functional arguments. This can be circumvented by using sufficiently unique variable names.

Because of the way variable values are stored, the main interpreter, _eval_, obviously does not use an A-list, and is therefore a function of only one argument. The function _evala_ defined in the BBN-LISP System will simulate the effect of the usual eval[x;a], _a_ being an A-list.

Different LISP systems employ different methods to achieve the following two effects in functions labelled FEXPR's in 7094 LISP. These two effects are (1) giving a function the ability to have an indefinite number of arguments, and (2) giving a function the ability to receive its arguments unevaluated.

On the 7094 an FEXPR is defined by putting the function definition on the property list after the flag, FEXPR, and treating it as a special case in the interpreter. In BBN-LISP we call functions which have abilities (1) and (2) FEXPR's, but we define them differently. The way an FEXPR is defined in BBN-LISP is as follows: instead of the usual lambda followed by a list of variables, the defining form is preceded by nlamda followed by a list containing a single variable. When a function with an nlamda is entered, everything following the function name in the form to be evaluated is placed on a single list and becomes the value of the single argument of this FEXPR. This is passed to the function unevaluated. In order to evaluate any portion of this list, an explicit call to eval must be made. See "defineq" in the listings for an example of the use of this device. A

third reason FEXPR's and FSUBR's are used on 7094 LISP is to
make the A-list available to a program. However, since
there is no A-list in BBN-LISP this will not concern us here.

Another major difference between BBN-LISP and 7094 LISP is
due to the fact that the 7094 has floating point hardware,
and the PDP-1 does not. Any floating point machinery would
have to be interpreted on the research computer. This would
be expensive in both time and space, and, therefore, in this
version of LISP there is only integer arithmetic. A compiler
is being planned for the PDP-1 and will be described in a
later document.

SECTION III.

DESCRIPTION OF FUNCTIONS IN BBN-LISP

cons[x;y]
SUBR

cons constructs a dotted pair of x and y. If y is a list, x becomes the first element of that list.

car[x]
SUBR

car gives the first element of a list x, or the left element of a dotted pair x. Nominally undefined for atoms, it gives the binding (value) of an atom x.

cdr[x]
SUBR

cdr gives the tail of a list (all but the first element). This is also the right member of a dotted pair. If x is an atom, cdr[x] gives the property list of x.

caar[x] = car[car[x]]
SUBR
cadr[x] = car[cdr[x]]
SUBR
cddddr[x] = cdr[cdr[cdr[cdr[x]]]]
SUBR

All 30 combinations of nested cars and cdrs up to 4 deep are included in the system.

eq[x;y]
SUBR

The value of eq is T if x and y are identical atoms, including numbers; otherwise the value is NIL. (Will give T for lists if their internal representations are identical, NIL otherwise.)

null[x]
  SUBR

eq[x;NIL]

atom[x]
  SUBR

Its value is T if $\underline{x}$ is an atom; NIL otherwise.

oblist[]
  SUBR

Gives a list of all atoms in the system.

not[x]
  EXPR

Its value is true if its argument is false, and false otherwise.

quote[x]
  FSUBR

This is a function that prevents its argument from being evaluated. Its value is $\underline{x}$ itself.

cond[x]
  FSUBR

The argument for cond is a list. Each element of the list is itself a list containing $n \geq 1$ items: the first is an expression whose value may be false or true (that is, NIL, or anything which is not NIL); the rest may be any expressions. This is the conditional expression in the LISP system. The meaning of it is: if the first element of the first list is true (not NIL), then the following expressions are evaluated. The value of the conditional is the value of the last expression in this sublist. If there is only one expression, then the value of

the conditional is the value of
this expression. This value co-
incides with the value in 7090
LISP for pairs of items, but
allows additional flexibility.
If the first element of the first
list is false (= NIL), then the
second sublist is considered, etc.
Thus, the arguments are searched
until a first element of a list
is found which is not NIL. If
none are found, the value of the
conditional expression is NIL.

prog[l]
  FSUBR

This feature allows the user to
write an ALGOL-like program con-
taining LISP statements to be
executed. The argument is a list,
the first element of which is a
list of program variables. The
rest of the list is a sequence of
statements, and atomic symbols
used as labels for transfer points.

go[x]
  FSUBR

go is the function used to cause a
transfer in prog. (GO A) will
cause the program to continue at
the label A.

list[x1;...;xn]
  FSUBR

The value of list is a list of
the values of its arguments.

return[x] SUBR	return is the normal end of a prog. Its argument is evaluated and is the value of the prog in which it appears.
print[x] SUBR	Prints x, followed by carriage return, on specified devices (see punchon, typeout). Value is x.
prin1[x] SUBR	Prints one atom, x, with no space or carriage return following. Value is x.
terpri[] SUBR	Prints a carriage return. Value is NIL.
punchon[x] SUBR	Turns punch on for print if x = T; turns punch off if x = NIL. Value is former setting of punchon.
typeout[x] SUBR	If x = T, turns typewriter on for printing. If x = NIL, turns typewriter off. Value is former setting of typeout.
read[] SUBR	Reads on S-expression from specified device (see typein).
punch[x] EXPR	This function sets punchon to t, sets typeout to nil, punches x, and then restores punchon and typeout to their original values.

typein[x]
   SUBR

If x = T read-in device is set to typewriter. If x = NIL read-in device is set to reader. Value is former setting of typein.

ratom[]
   SUBR

Reads in one atom from read-in device. Separation of atoms is as defined by the functions setsepr and setbrk.

setsepr[x]
   FSUBR
setbrk[x]
   FSUBR

These are both FSUBRS and may have up to 18 arguments each. Arguments should be octal numbers, e.g., 77q for carriage return. Characters defined by setbrk will delimit atoms and be returned as separate atoms themselves. Characters defined by setsepr will not be returned and will serve only to separate atoms. For example, to make ratom read in ordinary format, space (0q), comma (33q), and carriage return (77q) are separation characters, and left paren (57q), right paren (55q), and period (73q) are break characters. Thus setsepr[0q 33q 77q]
        setbrk[57q 55q 73q]
would set up these characteristics. The value of setsepr and of setbrk is NIL.

clearbuf[ ]
SUBR

This SUBR clears the input and output buffers of the sequence break package, including the sequence break reader, ratom, read, and typein line buffers, and sets the case to lower case. This means that if you have just done a read and the S-expression did not complete a line, whatever else is on that line will be lost. However, it is very useful if you want to initialize the system, or an error has been made, and you want to clear out what has been read in on a line.

readin[x]
SUBR

If x = T, readin sets the teletype input to the paper tape reader. Specifically, it eliminates the line-feed echo after a carriage return, and the delete characters, rubout and colon, are not recognized. Setting x to NIL restores the status to normal. This function returns its previous value.

feed[n]
SUBR

The value of n must be a number. This function outputs on the teletype n carriage return-line feeds or n carriage returns depending on the setting of readin.

character[n]
  SUBR

This function outputs on the teletype a single character with octal representation (code) n. n must be a number.

prog1[x;y]
  SUBR

This function evaluates both its arguments in order, that is, x first and then y, and then returns the value of x.

prog2[x;y]
  SUBR

The purpose of this function is to allow the evaluation of x, before returning y.

progn[x;y;...;z]
  FSUBR

progn is an FSUBR which evaluates each of its arguments in sequence, and returns the value of its last argument as its value. It is an extension of prog2.

set[x;y]
  SUBR

This function sets the atom which is the value of x, to the value of y, and returns the value of y.

setq[x;y]
  FSUBR

This FSUBR is identical to set, except that the first argument is quoted.
  Example: If the value of x is c, and the value of y is b, then set [x;y] would result in c having value b, and b returned. setq[x;y] would result in x having value b, and b returned. The value of y is unaffected.

setn[x;y]
  SUBR

setn requires and checks for an atom
as the value of the first argument,
and a number as the second. If the
first argument is not already de-
fined as a number, the value of the
second will be moved to a new cell
in FWS (Full Word Space), the loca-
tion of which will be stored in the
value cell of the first argument.
Otherwise, setn replaces the FWS cell
containing the previous numeric
value of the first argument by the
numeric value of the second. If the
second argument was the most recent
number added to FWS, the cell con-
taining its value is returned to the
free list.

  Example:
(SETN (QUOTE P) (PLUS P 1))
creates a new cell in FWS containing
the old value of P plus 1. This
value gets moved to the FWS cell con-
taining the old value.

The following will lose:
(PROG .. (SET (QUOTE A) B)
(SETN (QUOTE A) (PLUS A 1)) ...)
because the cell containing the value
of A is the same as that for B. To
avoid the problem, the first SET
should have been a SETN so that a
unique numeric value cell would have
been assigned for A.

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setqq[x;]	Identical to setq except that neither argument is evaluated.
setnq[x;y] FEXPR	This FEXPR is identical to setn except that the first argument is quoted.
putd[x;y] SUBR	putd places the value of y into the function cell of the atom which is the value of x. This is the basic way of defining functions. putd is mnemonic for put definition on x. Value of putd is the definition (value of y).
putdq[x;y] FEXPR	This function is similar to putd, but both arguments are considered quoted, and its value is x.
getd[x] SUBR	This function gets the definition of the function whose name is the value of x. If x is not a defined function, the value of getd[x] is NIL; if x is a SUBR or FSUBR, the value is a number.
fntyp[x] SUBR	This function gives EXPR, FEXPR, SUBR, FSUBR or NIL depending on whether x is an EXPR, FEXPR, SUBR, FSUBR or not defined, respectively.
eval[x] SUBR	eval evaluates the expression x and returns this value.

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errorset[form;arg] SUBR	This function calls <u>eval</u> with the value of <u>form</u>, and returns with a list of this value if no error is encountered. If an error is encountered on the call to <u>eval</u>, <u>errorset</u> returns with the value NIL. If <u>arg</u> is T, the message from <u>error</u> is printed; the message is not printed if arg = NIL.
ersetq[x] FEXPR	This FEXPR is defined as (ERRORSET (CAR X) T); that is, it is the same as <u>errorset</u> with the argument quoted and the error flag set to T.
nlsetq[x] FEXPR	This FEXPR is identical to <u>ersetq</u> except that the error flag is set to NIL and the error comment from <u>error</u> will not be printed out.
error[x] SUBR	<u>error</u> induces an error with message <u>x</u>.
quit[ ] SUBR	<u>quit</u> induces a "strong" error, i.e., will unwind a program through <u>errorsets</u> to the top level.
equal[x;y] SUBR	The value of this function is T if <u>x</u> and <u>y</u> are equal, that is, identical S-expressions, and NIL otherwise. It is as fast as <u>eq</u> for atoms.

and[x]
   FSUBR

This function is an FSUBR and can take an indefinite number of arguments. Its value is T if none of its arguments has value NIL, and is NIL otherwise.

or[x]
   FSUBR

or is also an FSUBR and may have an indefinite number of arguments (including 0). or has value NIL if all of its arguments have value NIL, otherwise, it has value T.

rdflx[x]
   EXPR

If x is NIL this function will try to read one S-expression from the typewriter with read[ ]; if no error occurred in reading, it will return with list of the S-expression that was read. If an error occurs in reading, it returns with NIL. If x is not NIL, it will attempt to read an S-expression and keep attempting to read it until it gets one without an error; each time it tries to read an S-expression and gets an error, it will print out x. In this case it returns with the S-expression itself (not list of the S-expression).

append[x;y]
   EXPR

This function copies list x and appends list y to this copy. The value is the combined list.

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nconc[x;y]
  SUBR

This function is similar to append, in effect, but it actually causes this effect by modifying the list structure x, and making the last element in the list x point to the list y. The value of nconc is a pointer to the first list x, but since this first list has now been modified it is a pointer to the concatenated list.

nnconc[x;y]
  SUBR

This function is the same as nconc. nnconc is used by the trace programs so that nconc itself can be traced.

attach[x;y]
  EXPR

This function attaches x to the front of the list y by doing an rplaca and an rplacd.

tconc[x;p]
  EXPR

This function provides an efficient way for placing an item x at the end of a list p. This list is the first item on p, that is, car[p]; cdr[p] is a pointer to the last element in this list; x is placed on the end of the list by modifying this structure, and x is placed on the list as an item. The effect of this function is equivalent to nconc[car[p]; list[x]], with cdr[p] updated to point to the last element of the modified list.

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lconc[x;p]
  EXPR

This function is similar to tconc, except that in this case x is a list. An entire list will be tacked on the end of car[p], and cdr[p] will be adjusted to be a pointer to the last element of this new combined list. Both tconc and lconc work correctly given null arguments.

last[x]
  EXPR

This function has as its value a pointer to the last cell in the list x, and returns NIL if x is an atom.

length[x]
  EXPR

This function has as a value the length of the list x. If x is an atom, it returns 0.

prettyprint[x]
  EXPR

The argument of prettyprint is a list of names of functions; it prints and/or punches (depending on the settings) the definitions of the named functions in a pretty format. It utilizes the functions printdef, endline, and superprint. This latter function does all the work.

prettydef[x]
  EXPR

This function of one argument (a list of function names) prints and/or punches "(DEFINEQ", followed by the prettyprint listing of each of

these functions, followed by a right paren. A tape punched by <u>prettydef</u> can be loaded by the function <u>load</u> if a STOP is punched on the end of the tape. The value of <u>prettydef</u> is <u>x</u>.

define[x]
  EXPR

The argument of <u>define</u> is a list. Each element of the list is itself a list containing either two or three items. In a two-item list the first item of each element of the list is the name of a function to be defined, and the second item is the defining lambda or nlamda expression. In a three-item list the first item is again the name of the function to be defined. The second is the lambda list of variables and the third is the form for the expression. As an example consider the following two equivalent expressions for defining the function null.

1)   (NULL (LAMBDA (X) (EQ X NIL)))
2)   (NULL (X) (EQ X NIL))

defineq[x;...;z]
    FEXPR

This FEXPR is closely related to define. However, it can take an indefinite number of arguments, and it will treat them literally, as if they were quoted. Each of the arguments must be a list of the form described as an element of the list which is the argument for define. Using defineq instead of define allows one to eliminate two pairs of parentheses in writing functions to be defined for loading with the function load.

load[x]
    EXPR

load is a function which reads successive S-expressions from the paper tape reader, and evaluates each as it is read. If $x = T$, then load prints the value; otherwise it does not. load continues reading S-expressions and evaluating them, until it reads the single atom STOP followed by a carriage return, at which point it returns the value NIL. Using load is the standard way of getting functions in from the paper tape reader; it saves having to write sequences of E(EVAL (READ)).

unpack[x]
  SUBR

The argument of <u>unpack</u> should be an atom. The value of <u>unpack</u> is a list which contains, in order, the characters which make up the print name of that atom.

pack[x]
  SUBR

The argument x of <u>pack</u> must be a list of atoms. The value of <u>pack</u> is a single atom whose print name is a packed version of the print names of all the atoms given in the list. Thus
pack[(a bc def g)] = abcdefg.

remob[x]
  SUBR

The argument of <u>remob</u> must be an atom. The effect of applying <u>remob</u> to this atom is to remove all trace of this atom from the system. This is a good way of reclaiming space from atoms which are no longer needed but it is very dangerous, and <u>remob</u> should be used with care. A future mention of the same atom name will have no connection with the old one that was formerly there. In addition, any lists which point to this old atom will now be incorrect.

member[x;y]
  SUBR

This SUBR checks to see if x is a member of the list y. If so, it returns the value T; if not, it returns the value NIL.

rplacd[x;y]
SUBR

This very dangerous SUBR places in the decrement of the cell pointed to by x the pointer y. Thus it changes the internal list structure physically, as opposed to _cons_ which creates a new list element. This is the only way to get a circular list inside of LISP; that is by placing a pointer to the beginning of a list in a spot at the end of the list. Using this function carelessly is one of the few ways to really clobber the system.

rplaca[x;y]
SUBR

This SUBR is similar to _rplacd_, but it replaces the address pointer of x with y. The same caveats which applied to using _rplacd_ apply to _rplaca_.

gensym[]
SUBR

This function of no argument generates a unique symbol of the form Annnn, in which each of the n's is replaced by a digit. Thus the first one generated is A 0001, etc. This is a way of generating new atoms for various uses within the system.

disp[x y]
SUBR

This function displays one point on the cathode ray tube at the point whose coordinates are $(x;y)$ and returns T if the light pen saw the displayed point, and NIL otherwise.

displis[·]]
SUBR

The argument of this function is a
list of successive x and y coordi-
nates to be displayed.
For example:
displis[(1 2 1 3 1 4)]
will successively display the
points at coordinates
(1,2), (1,3) and (1,4).
This is faster than displaying each
of these three points individually
by using disp.

logand[x;...;z]
FSUBR

This FSUBR will take the logical
AND of all of its argument as
octal numbers and return this value.

logor[x;...,z]
FSUBR

This function, an FSUBR, will take
the logical OR, bit-wise, of all of
its arguments, and return this
number

e[x]
FEXPR

This FEXPR is defined as eval; how-
ever, it is shorter and it removes
the necessity for the extra pair of
parentheses for the list of argu-
ments for eval. Thus, when typing
into evalquote one can simply type
e followed by whatever one would
type into eval and have it evaluated.

get[x;y]
  EXPR

This function gets from the list _x_ the item after the atom _y_ on list _x_. If _y_ is not on the list _x_, this function returns NIL. For example, get[(a b c d);b] = c.

trace[x]
  EXPR

This function has as an argument a list of names of functions. It changes the definition of these functions so that when each function is entered, the values of the arguments of this function are printed; when the value of this function is computed this value is printed. Thus, trace[(plus ratom)] would cause _plus_ and _ratom_ to be redefined so that this tracing takes place. The value of _trace_ is the value of its argument _x_. The work of _trace_ is done by the function _trac1_.

tracp[x;y]
  EXPR

This function tells whether the function named _x_ with definition _y_ has been traced. Its value is **T** if the function is being traced, and NIL otherwise.

untrace[x]
  EXPR

This function undoes what _trace_ does, and restores the original definition of the function.

A word of warning: do not trace
the following functions or you
will get in an infinite loop be-
cause these functions are used
within _trac1_ itself:
print; _cons_; _set_; _fntyp_; _eval_;
return; _evalprint_; _car_; _cdr_;
null; _go_.

mapc[x;fn]
  EXPR

This function applies the function
_fn_ to each of the elements of the
list _x_. It returns the value NIL.

mapcar[x;fn]
  EXPR

This function applies the function
_fn_ to each of the elements of the
list _x_. It creates a new list
which is a map of the old list in
the sense that each element of
the new list is the value of
applying _fn_ to the corresponding
element of the old list.

mapconc[x;fn]

Identical to _mapcar_ except that
it does an _nconc_ instead of a
cons.

mapcon[x;fn]

Identical to _maplist_ except that
it does an _nconc_ instead of a
cons.

map[x;fn]
   EXPR

This function applies the function _fn_ to successive tails of the list _x_. That is, first it computes fn[x], and then fn[cdr[x]], etc. until _x_ is NIL. This function returns NIL.

maplist[x;fn]
   EXPR

This function computes successively the same values that _map_ computes; it forms a new list consisting of successive values of applications of this function.

assoc[x;a]
   EXPR

If _a_ is a list of dotted pairs, then _assoc_ will produce the first pair whose first item is _x_. If such an item is not found, _assoc_ will return NIL.

sassoc[x;y:u]
   EXPR

The function _sassoc_ searches _y_, which is a list of dotted pairs, for a pair whose first element is _x_. If such a pair is found, the value of _sassoc_ is this pair. Otherwise, the function _u_ of no arguments is taken as the value of _sassoc_.

copy[x]
   EXPR

This function makes a copy of the list _x_. The value of _copy_ is the location of the copie list.

intersection[x;y]
  EXPR

This function returns with a list whose elements were members of both lists x and y.

union[x;y]
  EXPR

This function is entered with two lists. It returns with a list consisting of all elements included on either of the two original lists. If the same item is a member of both original lists, it is included only once on the new list.

prop[x;y;u]
  EXPR

The function prop searches the list x for an item that is equal to y. If such an element is found, the value of prop is the rest of the list beginning immediately after that element. Otherwise, the value is u[], where u is a function of no arguments.

reverse[l]
  EXPR

This is a function to reverse the top level of a list. Thus, using reverse on
(A B (C D)) = ((C D) B A)

subst[x;y;z]
  EXPR

This function gives the result of substituting the S-expression x for all occurrences of the atomic symbol y in the S-expression z.

sublis[x;y] EXPR	Here $\underline{x}$ is a list of pairs: $$((u_1 \cdot v_1)\ (u_2 \cdot v_2)\ \cdots\ (u_n \cdot v_n))$$ The value of sublis[x;y] is the results of substituting each $\underline{v}$ for the corresponding $\underline{u}$ in $\underline{y}$.
evala[x;a] SUBR	This is the regular _eval_ in the 7094 LISP. Its first argument is a form which is evaluated by using the values obtained from $\underline{a}$, a list of dotted pairs. That is, any variables appearing in $\underline{x}$ that also appear on $\underline{a}$ will be given the value indicated on $\underline{a}$.
apply[fn;args;a] SUBR	_apply_ applies the function $\underline{fn}$ to the arguments $\underline{args}$ with the values obtained from $\underline{a}$, i.e. the arguments of $\underline{fn}$ on $\underline{args}$ are _not_ evaluated but given to $\underline{fn}$ directly. $\underline{a}$ is used to evaluate free variables in $\underline{fn}$ as described above.
remove[x;l] EXPR	The function _remove_ removes all occurrences of $\underline{x}$ from list $\underline{l}$.
remprop[x;y] EXPR	This function _removes_ all occurrences of the _property_ with label $\underline{y}$ from the property list of $\underline{x}$.
put[x;y;z] EXPR	This function _puts_ on the property list of $\underline{x}$, the label $\underline{y}$ followed by the property $\underline{z}$. The current value of $\underline{z}$ replaces any previous value of $\underline{z}$ with label $\underline{y}$ on this property list.

add[x;y;z]
  EXPR

This function <u>adds</u> the value <u>z</u> to the list appearing under the property <u>y</u> on the atom <u>x</u>. If <u>x</u> does not have a property <u>p</u>, the effect is the same as put[x;y;list[z]].

getp[x;y]
  EXPR

This function <u>gets</u> the <u>property</u> with label <u>y</u> from the property list of <u>x</u>.

NOTE: Both <u>prop</u> and <u>get</u> may also be used on property lists. However, since <u>getp</u> searches a list two at a time, the latter allows one to have the same object as both a property and a value. e.g., if the property list of <u>x</u> is (PROP1 A PROP2 B A C)

      then **get**[x;A] = PROP2,
      but **getp**[x;A] = C.

deflist[x;ind]
  EXPR

This function is used to put any indicator on a property list. The first argument is a list of pairs (where the first of the pair is a name and the second party of the pair is the property to be stored with the indicator on the property list of the name) and the second argument is the indicator that is to be used.

select[x;y_1;y_2 ...;y_n;z]
  FSUBR

An example of arguments for this function is:

[q; (q_1 e_1); (q_2 e_2); ...(q_n e_n); e]

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The q_i's are evaluated in sequence
until one is found such that $q_i =$
q, and the value of <u>select</u> is the
value of the corresponding e_i. If
no such q_i is found the value of
<u>select</u> is that of e.

selectq[x;y;z]   <u>selectq</u> is identical to <u>select</u> ex-
  FSUBR   cept that the q_i's are not evalu-
                  ated--only q.

time[x n]   **This** function performs computation
  EXPR   <u>x</u> <u>n</u> times and indicates average time
                  in tenths of seconds.

gcgag[x]   If x=T garbage collector will
  SUBR   print message when entered. If
                  x=NIL, no message is printed.

reclaim[]   This function initiates a garbage
  SUBR   collection and returns with the
                  number of available LISP words in
                  free storage.

field[n]   This function calls field <u>n</u> from
  SUBR   the drum. (See description of
                  system program linking.)

nth[x;n]   This EXPR has as inputs a list <u>x</u>
  EXPR   and a positive integer <u>n</u>. Its
                  value is a list whose first element
                  is the <u>nth</u> element of list <u>x</u> Thus
                  if <u>n</u> = 1, it returns the list <u>x</u> it-
                  self. If n = 2, it returns cdr[x].
                  If n = 3, it returns cddr[x], etc.

editf[x]
  EXPR

This EXPR gets the expression which is the definition of the function named $\underline{x}$ and gives it to edite.

editv[x]
  EXPR

This EXPR gets the value of the atom $\underline{x}$ and gives it to edite for editing.

editp[x]
  EXPR

This EXPR gets the property list of the atom $\underline{x}$, etc.

edite[x]
  EXPR

This function is the executive for an editing facility for LISP expressions. The argument of edite must be a list to be edited. When edite has been called, it prints out EDIT, and then waits for input from the on-line teletype (or the reader if typein is set to NIL).

The input that may be typed in may be a positive integer, a negative integer, or zero, or one of these as the first element of a two-element list, or NIL, or one of several special lists described below. Typing in NIL terminates editing.

This editing program allows you to edit any subexpression within the current level expression, that is, you can replace or delete any subexpression of this expression, or insert anything before any subexpression of this expression. An

input (n exp) where n is a positive
integer will replace the nth expres-
sion in the current level expression
by exp; if n is a negative integer
it will put exp just before the nth
subexpression in the current level
expression. (n) where n is a posi-
tive integer (with no expression
following this integer) will delete
the nth expression.

Warning: Typing "(1)", where current
 expression is a singleton, will not
 have desired effect.

An input of 0 will take you up to
the next higher level expression.
If the input to edit is a positive
integer, the nth-subexpression of
the current expression will become
the expression that can be edited.

An important thing to note is that
all editing is final in the sense
that any changes that are requested
are put in with rplacas and rplacds.
It is the original expression which
has been modified to give the edited
version; to return to the original
expression you must re-edit. How-
ever, by using the COPY and RESTORE
feature, the user can protect him-
self against errors in editing. The
function edite calls edit1f, edit2f,
edit2af, and edit3f to do all the work.

Other special commands are:

COPY   copies and saves entire
                expression being edited
                as it currently exists.

RESTORE   Restores expression as
                of last copy: the
                current level expression
                will be the current level
                expression at last copy
                RESTORING without copying
                will have no effect.

p   Same as (p 0).

(p n)   Prints the $\underline{n}$th subexpres-
                sion of the current ex-
                pression to a level of 2,
                using LEVELN described be-
                low. If n is zero, prints
                current expression to
                level 2.

(p n m) Prints $\underline{n}$th subexpression
                to a level m.
                All printing may be interupted.

$(N\ e_1\ e_2\ \ldots)$

which will tack the expressions
$e_1\ e_2,\ \ldots$ to the end of the current
expression.

(E exp) will print the value of
eval [exp]. (I n exp) will compute
v = eval[exp] and then act as if
edit were given (n v). This allows
you to insert the value of a compu-
tation in the current expression, at
subexpression $\underline{n}$. ($\underline{n}$ must be a num-
ber).

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(LI n) will insert a left parenthesis
immediately before subexpression n̲
in the current expression and a match-
ing right paren at the end of this
current expression. For example, if
e = (A B C)
(LI 2) yields (A (B C)).

(LO n) will remove a left paren from
the nth subexpression, and take a
corresponding right paren from the
end of the current expression, e.g.,
for e = (A (B C) D)
(LO 2) yields (A B C)

(RO n) will remove a right paren
from the nth subexpression of the
current expression, and insert one
in at the end of the current top
level expression, e.g.,
for e = (A (B C) DE)
(RO 2) yields (A (B C DE))

(RI m n) will insert a right paren
in the nth subexpression of the mth
subexpression of the current expres-
sion, removing one from the end of
the mth subexpression, e g.,
for e = (A B (C D E) F)
(RI 3 1) yields
(A B (C) D E F)

leveln[x n]

Abbreviates list x at level n, using
the symbol ampersand, "&," to indi-
cate greater depth. For example,
leveln [(A (B C) (D (E F) G)) 2] is
(A (B C) (D & G)).

The following 9 functions form a Break Package which allows the
user to make a break conditional upon the result of some computa-
tion and thus arrest the operation of a function. He may interro-
gate the broken function as to the current values of its arguments
or other variables, or perform arbitrary LISP computations; then
he may return with a specified value for it without actually
entering it. Alternatively, the user may just "crack" a function,
i.e., print out the result of some computation before executing
the function and print out the final value of this function.

break[fn;when;what]
  EXPR

break is a function of three argu-
ments: the function to be broken,
under what condition to break, and
what to print out when a break occurs
If when = T, the function always
breaks. If when = (NIL) a crack is
made in fn. If what = NIL, no
information is printed out. break
redefines fn using break1 so that at
the time the function would have
been entered, break1 is entered
instead with the definition of the
function and information regarding
the conditions for breaking.

unbreak[fn]
  EXPR

unbreak redefines fn as it was before
the break and returns the value fn.
If fn is not broken when unbreak is
called, the value of unbreak is
(FN NOT BROKEN).

breaklist[l]   breaklist is a function of one argu-
  FEXPR   ment, a list of function names. It

performs (BREAK FN T NIL) for each

function name and returns the list

of values of break. Note that

(BREAK FN T NIL) will cause fn always

to break, and will not print out

any special message.

unbreaklist[l]   This function performs (UNBREAK FN)
  FEXPR   for each function on the list l.

breakat[fn;where;when;what] This function is similar to break
  EXPR   except that instead of inserting a

break at the beginning of fn, it

allows the user to insert a break

at any top-level place in fn. The

argument where indicates the label

or statement at which the break is

to occur. The other arguments are

used as in break.

unbreakat[fn;where]   This function removes a break in-
  EXPR   serted by breakat.

breakprog[fn;l]   breakprog is entered with the name
  EXPR   of a function and a list of places

in that function where a break is

desired. breakprog performs

(BREAKAT FN WHERE T NIL) for each

place on the list l.

unbreakprog[fn]
  EXPR

This function performs
(UNBREAKAT FN WHERE)
for each place where a break
exists in _fn_.

break1[form;when;fn;what]
  FEXPR

Although this function is not
entered directly by the user, it is
the heart of all the break functions
and is entered when a break occurs.
After the specified information is
printed out, break1 listens to the
typewriter or teletype for inputs.
If STOP is input, a normal,
exit is achieved. If RETURN FOO
is input break1 returns (EVAL FOO).
If QUIT is input, it performs
(ERROR FN). If EVAL is input, it
evaluates _fn_. If a normal exit is
subsequently achieved via the STOP
command, break1 does not reevaluate
_fn_, but uses the value obtained by
the EVAL command. The EVAL
feature is useful for evaluating a
broken function without "letting go"
of the break, e.g., to examine the
effect of executing a broken func-
tion. If OK is input, a normal
return is made without printing the
value of the function. Any other
input to break1 is evaluated, and
its value printed. This function
uses bp1 to do part of its work.

Arithmetic Functions   (all arguments must be numbers)

greaterp[x;y]   T if $x > y$;
   SUBR   NIL otherwise

lessp[x;y]   T if $x < y$;
   EXPR   NIL otherwise

zerop[x]   T if x is zero;
   EXPR   NIL otherwise

minusp[x]   T if x is negative;
   EXPR   NIL otherwise

numberp[x]   T if x is a number;
   SUBR   NIL otherwise

add1[x] $x + 1$
   EXPR

sub1[x] $x - 1$
   EXPR

plus[x;y] $x + y$ (This FSUBR may have any
   FSUBR   number of arguments.)

minus[x]   - x
   SUBR

times[x;y]   product of x and y   (This FSUBR
   FSUBR   may have any number of
                                               arguments.)

quotient[x;y] SUBR	greatest integer in quotient x/y
difference[x;y] EXPR	This function has for its value the algebraic difference between its arguments.
remainder[x;y] EXPR	This function computes the number theoretic remainder for fixed-point numbers.
divide[x;y] SUBR	This function yields a dotted pair whose first member is quotient[x;y] and whose second member is remainder [x;y]. Remainder is defined in terms of divide.

Following is a list of all atoms with APVAL's (permanent values) in the basic system and their values.

blank	space
space	space
tab	tab
comma	,
eqsign	=
xeqs	=
f	nil
nil	nil
period	.
plus	+
lpar	(
rpar	)
slash	/
t	t
t	t
qmark	?
xdol	$
xsqu	'
xdq	"
xlbr	[
xrbr	]
xarr	←
uparr	↑
colon	:
xgreater	>
xlesser	<
xnum	#
xper	%
xamp	&
xat	@

LISTINGS OF S-EXPRESSIONS OF EXPR'S AND FEXPR'S

```
(prog nil
   (cond
      ((null (fntyp (quote putdq))) (putd (print (quote putdq))
(quote (nlamda (x) (prog2
         (putd (car x) (cadr x))
         (car x))))))))
(return (putdq load (lambda (x) (prog (xx yy zz)
   (clearbuf)
   (setq zz (typein nil))
11 (cond
      ((equal (setq xx (read)) (quote stop)) (return (prog2
         (clearbuf)
         (typein zz)))))
   (setq xx (eval xx))
   (cond
      (x (print xx)))
   (go 11))))))
```

```lisp
(putdq define
    (lambda (x) (cond
        ((null x) nil)
        (t (cons ((lambda (y) (prog2
             (putd (car y) (cond
                 ((null (cddr y)) (cadr y))
                 (t (cons (quote lambda) (cdr y)))))
            (car y)))
          (car x)) (define (cdr x)))))))

(putdq defineq
    (nlamda (x) (define x)))




(add
    (lambda (x y z) (prog nil
      loop   (cond
              ((null (cdr x)) (rplacd x (list
                y
                (list
                  z))))
              ((equal (cadr x) y) (rplaca (cddr x) (append
(caddr x) (list
                z))))
              ((setq x (cddr x)) 'go loop)))
          (return y))))

(add1
    (lambda (x) (plus
      x
      1)))

(append
    (lambda (x y) (cond
      ((null x) y)
      (t (cons (car x) (append (cdr x) y))))))
```

```
(assoc
    (lambda (xsas ysas) (cond
        ((null ysas) nil)
        ((equal (caar ysas) xsas) (car ysas))
        (t (assoc xsas (cdr ysas))))))

(attach
    (lambda (x y) (rplaca (rplacd y (cons (car y) (cdr y)))
x)))

(copy
    (lambda (x) (cond
        ((null x) nil)
        ((atom x) x)
        (t (cons (copy (car x)) (copy (cdr x)))))))

(deflist
    (lambda (l ind) (prog nil
        loop  (cond
                  ((null l) (return nil)))
              (put (caar l) ind (cadar l))
              (setq l (cdr l))
              (go loop))))

(difference
    (lambda (x y) (plus
        x
        (minus y))))

(e
    (nlamda (xeeee) (eval xeeee)))

(ersetq
    (nlamda (ersetx) (errorset (car ersetx) t)))

(get
    (lambda (x y) (cond
        ((null x) nil)
        ((equal (car x) y) (cadr x))
        (t (get (cdr x) y)))))
```

```lisp
(getp
    (lambda (x y) (prog (z)
            (setq z (cdr x))
        loop  (cond
                  ((null z) (return nil))
                  ((eq (car z) y) (return (cadr z))))
            (setq z (cddr z))
            (go loop)))))

(intersection
    (lambda (x y) (cond
        ((null x) nil)
        ((member (car x) y) (cons (car x) (intersection
(cdr x) y)))
        (t (intersection (cdr x) y)))))

(last
    (lambda (x) (prog (xx)
        l     (cond
                  ((atom x) (return xx)))
            (setq xx x)
            (setq x (cdr x))
            (go l))))

(lconc
    (lambda (x p) (prog (xx)
            (return (cond
                  ((null x) p)
                  ((cdr (setq xx (last x))) (error (list
                      (quote lconc)
                       x)))
                  ((null p) (cons x xx))
                  ((null (car p)) (rplaca (rplacd p xx) x))
                  (t (prog2
                      (rplacd (cdr p) x)
                      (rplacd p xx)))))))))

(length
    (lambda (x) (prog (n)
            (setq n 0)
        l     (cond
                  ((atom x) (return n)))
            (setq x (cdr x))
            (setq n (add1 n))
            (go l))))

(lessp
    (lambda (x y) (cond
        ((equal x y) nil)
        ((greaterp x y) nil)
        (t t))))
```

```
(map
    (lambda (mapx mapf) (cond
        ((null mapx) nil)
        (t (prog2
            (mapf mapx)
            (map (cdr mapx) mapf))))))

(mapc
    (lambda (mapcx mapcf) (cond
        ((null mapcx) nil)
        (t (prog2
            (mapcf (car mapcx))
            (mapc (cdr mapcx) mapcf))))))

(mapcar
    (lambda (mpcrx mpcrf) (cond
        ((null mpcrx) nil)
        (t (cons (mpcrf (car mpcrx)) (mapcar (cdr mpcrx) mpcrf
)))))))

(mapcon
    (lambda (mpcnx mpcnf) (cond
        ((null mpcnx) nil)
        (t (nconc (mpcnf mpcnx) (mapcon (cdr mpcnx) mpcnf
)))))))

(mapconc
    (lambda (mpcncx mpcncf) (cond
        ((null mpcncx) nil)
        (t (nconc (mpcncf (car mpcncx)) (mapconc (cdr mpcncx) mpcncf
)))))))

(maplist
    (lambda (mplstx mplstf) (cond
        ((null mplstx) nil)
        (t (cons (mplstf mplstx) (maplist (cdr mplstx) mplstf
)))))))

(minusp
    (lambda (x) (greaterp 0 x)))

(nill
    (nlamda (xnil) nil))

(nlsetq
    (nlamda (nlsetx) (errorset (car nlsetx) nil)))
```

```
(not
    (lambda (x) (cond
        ((null x) t)
        (t nil)))))

(prop
    (lambda (x y u) (cond
        ((null x) (u))
        ((equal (car x) y) (cdr x))
        (t (prop (cdr x) y u)))))

(punch
    (lambda (x) (prog (y z)
                (setq y (punchon t))
                (setq z (typeout nil))
                (print x)
                (punchon y)
                (typeout z)
                (return x))))

(put
    (lambda (x y z) (prog nil
        loop   (cond
                    ((null (cdr x)) (rplacd x (list
                        y
                        z)))
                    ((equal (cadr x) y) (rplaca (cddr x) z))
                    ((setq x (cddr x)) (go loop)))
                (return y))))

(rdflx
    (lambda (x) (prog (xx yy)
                (setq yy (typein t))
                (cond
                    (x (go r1)))
                (setq xx (ersetq (read)))
                (go r2)
        r1      (cond
                    ((setq xx (nlsetq (read))) (setq xx (car xx
)))
                    ((print x) (go r1)))
        r2      (typein yy)
                (return xx))))
```

```
(remainder
    (lambda (x y) (cdr (divide x y))))

(remove
    (lambda (a x) (cond
        ((null x) nil)
        ((equal a (car x)) (remove a (cdr x)))
        (t (cons (car x) (remove a (cdr x)))))))

(remprop
    (lambda (x y) (prog nil
        loop  (cond
                ((null (cdr x)) (return y))
                ((equal (cadr x) y) (rplacd x (cdddr x)))
                (t (setq x (cdr x))))
        (go loop))))

(reverse
    (lambda (x) (prog (u)
        loop  (cond
                ((null x) (return u)))
              (setq u (cons (car x) u))
              (setq x (cdr x))
              (go loop))))

(sassoc
    (lambda (xsas ysas usas) (cond
        ((null ysas) (usas))
        ((equal (caar ysas) xsas) (car ysas))
        (t (sassoc xsas (cdr ysas) usas)))))

(setnq
    (nlamda (xsetnq) (setn (car xsetnq) (eval (cadr xsetnq)
))))

(setqq
    (nlamda (x) (set (car x) (cadr x))))

(soundexin
    (nlamda (x) (mapcar x (quote (lambda (ysdx) (put (soundex
 ysdx) (quote name) ysdx))))))

(soundexout
    (lambda (x) (getp x (quote name))))

(sub1
    (lambda (x) (plus
        x
        -1)))
```

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```
(sub2
    (lambda (a z) (cond
        ((null a) z)
        ((equal (caar a) z) (cdar a))
        (t (sub2 (cdr a) z))))))

(sublis
    (lambda (a y) (cond
        ((atom y) (sub2 a y))
        (t (cons (sublis a (car y)) (sublis a (cdr y)))))))

(subst
    (lambda (x y z) (cond
        ((equal y z) x)
        ((atom z) z)
        (t (cons (subst x y (car z)) (subst x y (cdr z)))))))

(tconc
    (lambda (x p) (prog (xx)
                (return (cond
                    ((null p) (cons (setq xx (cons x nil)) xx))
                    ((null (car p)) (prog2
                        (rplaca p (cons x nil))
                        (rplacd p (car p))))
                    (t (rplacd p (cdr (rplacd (cdr p)
(rplacd (cons x (cdr p)) nil)))))))))))

(time
    (lambda (x n) (prog (y m c c1)
                (setq m n)
                (setq c (clock))
        t1      (cond
                    ((zerop m) (setq c1 (clock)))
                    (t (progn
                        (setq y (eval x))
                        (setq m (sub1 m))
                        (go t1))))
                (setq m (divide (plus
                    c1
                    (minus c)) n))
                (prin1 (car m))
                (prin1 period)
                (prin1 (quotient (times
                    (cdr m)
                    10) n))
```

```
            (prin1 blank)
            (print (quote seconds))
            (return y))))

(union
    (lambda (x y) (cond
        ((null x) y)
        ((member (car x) y) (union (cdr x) y))
        (t (cons (car x) (union (cdr x) y)))))))

(zerop
    (lambda (x) (equal x 0)))
```

```lisp
(break
    (lambda (fn when what) (prog (xx yy zz)
            (cond
                ((null (setq xx (getd fn))) (return (prog2
                    (putd fn (list
                        (quote nlamda)
                        (quote (1))
                        (list
                            (quote break1)
                            nil
                            when
                            (setq xx (list
                                fn
                                (quote (undefined))))
                            what)))
                xx)))
                ((eq (setq yy (fntyp fn)) (quote fsubr)) (return
  (cons fn (quote (is an fsubr)))))
                ((null (eq yy (quote subr))) (go b2)))
            (setq yy (rdflx (print (cons fn (quote (is a subr

need args)))))))
            (putd (setq zz (gensym)) xx)
            (setq xx (putd fn (list
                (quote lambda)
                yy
                (cons zz yy))))
        b2      (cond
                ((eq (caaddr xx) (quote break1)) (setq xx (
list
                (car xx)
                (cadr xx)
                (cadr (caddr xx)))))))
            (putd fn (list
                (car xx)
                (cadr xx)
                (list
                    (quote break1)
                    (caddr xx)
                    when
                    (list
                        fn)
                    what))))
            (return fn)))))
```

```
(unbreak
   (lambda (fn) (prog (xx yy)
               (return (cond
                    ((null (setq xx (getd fn))) (cons fn (quote
 (not a function)))))
                    ((and
                      (or
                         (eq (setq yy (fntyp fn)) (quote expr)
)
                         (eq yy (quote fexpr)))
                     (eq (caaddr xx) (quote break1))) (prog2
                     (putd fn (list
                        (car xx)
                        (cadr xx)
                        (cadr (caddr xx))))
                    fn))
               (t (cons fn (quote (not broken)))))))))))

(breaklist
   (nlamda (x) (maplist x (quote (lambda (x) (break (car x
) t nil)))))))

(unbreaklist
   (nlamda (x) (maplist x (quote (lambda (x) (unbreak (car
 x)))))))

(breakprog
   (lambda (bpx bpy) (maplist bpy (quote (lambda (z) (breakat
 bpx (car z) t nil)))))))

(unbreakprog
   (lambda (x) (prog (xx)
               (setq xx (bp1 x))
       u1      (cond
                   ((eq (caadr xx) (quote break1)) (rplacd xx
(cddr xx)))
                   ((setq xx (cdr xx)) (go u1))
                   (t (return nil)))
               (go u1))))
```

```lisp
(breakat
    (lambda (fn where when what) (prog (a)
            (setq a (bp1 fn))
    b1      (cond
                ((equal (car a) where) (return (prog2
                    (rplacd a (cons (list
                        (quote break1)
                        nil
                        when
                        (list
                            fn
                            (quote at)
                            where)
                    what) (cdr a)))
                where)))
                ((setq a (cdr a)) (go b1)))
            (return (cons where (quote (not found)))))))))

(unbreakat
    (lambda (fn where) (prog (a)
            (setq a (bp1 fn))
    u1      (cond
                ((equal (car a) where) (return (cond
                    ((eq (caadr a) (quote break1)) (prog2
                        (rplacd a (cddr a))
                        where))
                    (t (cons fn (append (quote (not broken at
)) (list
                        where)))))))
                ((setq a (cdr a)) (go u1)))
            (return (cons where (quote (not found)))))))))
```

```lisp
(break1
    (nlamda (brk1x) (prog (brk1xx brk1yy brk1zz)
                (cond
                    ((null (setq brk1xx (eval (cadr brk1x)))) (
return (eval (car brk1x))))
                    ((null (equal brk1xx (quote (nil)))) (go b0
)))
                (print (append (quote (crack in)) (caddr brk1x
)))
                (cond
                    ((cadddr brk1x) (print (eval (cadddr brk1x)
))))
                (go b3)
        b0      (setq brk1yy (print (append (quote (break in))
  (caddr brk1x))))
                (cond
                    ((cadddr brk1x) (print (eval (cadddr brk1x)
))))
        b1      (cond
                    ((eq (setq brk1xx (rdflx brk1yy)) (quote quit
)) (error (caddr brk1x)))
                    ((eq brk1xx (quote stop)) (go b3))
                    ((eq brk1xx (quote return)) (go b2))
                    ((eq brk1xx (quote eval)) nil)
                    ((eq brk1xx (quote ok)) (go b3))
                    ((and
                        (ersetq (setq brk1xx (eval brk1xx)))
                        (nlsetq (print brk1xx))) (go b1))
                    ((print brk1yy) (go b1)))
                (cond
                    ((null (setq brk1zz (ersetq (eval (car brk1x
))))) (print brk1yy))
                    ((print (append (caddr brk1x) (quote (evaluated
)))) (set (caaddr brk1x) (car brk1zz))))
                (go b1)
        b2      (cond
                    ((and
                        (setq brk1zz (rdflx nil))
                        (setq brk1zz (ersetq (eval (car brk1zz))
))) (go b4))
                    ((print brk1yy) (go b1)))
        b3      (cond
                    ((or
                        brk1zz
                        (setq brk1zz (ersetq (eval (car brk1x)))
)) nil)
                    ((print brk1yy) (go b1)))
        b4      (cond
                    ((eq brk1xx (quote ok)) (print (caddr brk1x
)))
                    ((prog2
                        (print (append (quote (value of)) (caddr
 brk1x)))
                        (null (nlsetq (print (car brk1zz)))))) (print
  (quote ok))))
                (return (car brk1zz)))))
```

```
(bp1
    (lambda (x) (prog (xx)
             (return (cond
                  ((and
                      (or
                         (eq (setq xx (fntyp x)) (quote expr))
                         (eq xx (quote fexpr)))
                       (eq (caaddr (setq xx (getd x))) (quote prog
))) (caddr xx))
                  (t (error (cons x (quote (not a program)))))
))))))
```

```
(prettydef
    (lambda (x) (prog (a)
                (setq a (punchon t))
                (prin1 (quote "("))
                (print (quote defineq))
                (prettyprint x)
                (print (quote ")");)
                (punchon a)
                (return x))))

(prettyprint
    (lambda (1) (map 1 (quote (lambda (j) (prog (t1)
                (terpri)
                (prin1 lpar)
                (print (car j))
                (printdef (cond
                    ((getd (car j)))
                    (t (quote undefined))))
                (prin1 rpar)
                (terpri))))))))

(printdef
    (lambda (e) (prog (1 iunit iunitl)
                (setnq 1 1)
                (setq iunit (quote "    "))
                (setq iunitl 3)
                (prin1 iunit)
                (superprint e)
                (return nil))))

(superprint
    (lambda (e) (cond
        ((atom e) (cond
            ((member e (quote (""" " " "(" ")"
"
" "    " "." ","))) (prin1 (pack (list
                (quote """)
                e
                (quote """)))))
            (t (prin1 e))))
        (t (prog (ep m)
                (setq ep e)
                (prin1 lpar)
```

```
a        (cond
            ((member (car ep) (quote (and
                or
                select
                selectq
                list
                plus
                times
                cond
                prog2
                progn))) (go pl))
            ((eq (car ep) (quote prog)) (go pp))
            ((atom (car ep)) nil)
            ((or
                (eq (caar ep) (quote lambda))
                (eq (caar ep) (quote nlamda))) (go pl
)))
         (superprint (car ep))
         (setq ep (cdr ep))
         (cond
            ((null ep) (return (prin1 rpar)))
            ((atom ep) (go pd)))
         (prin1 blank)
         (go a)
pk       (setnq i (sub1 i))
pd       (prin1 blank)
         (prin1 period)
         (prin1 blank)
         (prin1 ep)
         (return (prin1 rpar))
pl       (setnq i (add1 i))
         (superprint (car ep))
pm       (setq ep (cdr ep))
         (cond
            ((null ep) (go pj))
            ((atom ep) (go pk)))
         (endline)
         (superprint (car ep))
         (go pm)
pj       (setnq i (sub1 i))
         (return (prin1 rpar))
pp       (prin1 (car ep))
         (setq ep (cdr ep))
         (setnq i (add1 i))
         (cond
            ((null ep) (go pj))
            ((atom ep) (go pk)))
         (prin1 blank)
         (superprint (car ep))
py       (setq ep (cdr ep))
         (cond
```

```
                        ((null ep) (go pj))
                        ((atom ep) (go pk)))
                  (endline)
                  (cond
                     ((atom (car ep)) (go pz)))
                  (prin1 iunit)
                  (prin1 iunit)
        px        (setnq 1 (plus
                     1
                     2))
                  (superprint (car ep))
                  (setnq 1 (plus
                     1
                     -2))
                  (go py)
        pz        (prin1 (car ep))
                  (setnq m (plus
                     iunitl
                     iunitl
                     (minus (length (unpack (car ep))))))
        aa        (setnq m (sub1 m))
                  (prin1 blank)
                  (cond
                     ((null (or
                         (zerop m)
                         (minusp m))) (go aa)))
                  (setq ep (cdr ep))
                  (cond
                     ((null ep) (go pj))
                     ((atom ep) (go pk))
                     ((atom (car ep)) (go pz)))
                  (go px))))))

(endline
    (lambda nil (prog (j)
            (setnq j 1)
            (terpri)
        a      (cond
                  ((zerop j) (return nil))
                  ((minusp j) (error 1)))
            (prin1 iunit)
            (setnq j (sub1 j))
            (go a))))
```

```
(trace
    (lambda (x) (prog (a b c g)
                 (setq a x)
         loop    (cond
                    ((null x) (return a)))
                 (setq b (getd (setq c (car x))))
                 (setq x (cdr x))
                 (cond
                    ((null b) (progn
                        (print (cons c (quote (undefined))))
                        (go loop)))
                    ((tracp c b) (progn
                        (print (cons c (quote (was traced))))
                        (go loop))))
                 (putd (setq g (gensym)) b)
                 (putd c (list
                     (quote nlamda)
                     (quote (q1qq))
                     (list
                         (quote trac1)
                         (list
                             (quote quote)
                             c)
                         (list
                             (quote quote)
                             g)
                         (quote q1qq))))
                 (go loop))))

(untrace
    (lambda (x) (prog (a b c g)
                 (set (quote a) x)
         loop    (cond
                    ((null x) (return a)))
                 (set (quote g) (car x))
                 (set (quote x) (cdr x))
                 (cond
                    ((tracp g (set (quote b) (getd g))) (progn
                        (set (quote b) (cdaddr b))
                        (putd (cadar b) (getd (set (quote c) (cadadr
b)))))
                        (remob c)))
                    (t (print (cons g (quote (not traced))))))
                 (go loop))))
```

```lisp
(tracp
    (lambda (x y) (and
        (eq (fntyp x) (quote fexpr))
        (eq (caaddr y) (quote trac1))))))

(trac1
    (lambda (ctrac gtrac xtrac) (prog (atrac)
            (print (cons ctrac (quote (entered with))))
            (set (quote xtrac) (cond
                ((eq (fntyp gtrac) (quote fsubr)) (print xtrac
))
                ((eq (fntyp gtrac) (quote fexpr)) (print xtrac
))
                (t (evalprint xtrac))))
            (set (quote atrac) (eval (cons gtrac xtrac)))
            (print (cons ctrac (quote (has value))))
            (return (print atrac)))))

(evalprint
    (lambda (xvalp) (prog (avalp)
        loop  (cond
                ((null xvalp) (return avalp)))
            (set (quote avalp) (nnconc avalp (list
                (list
                    (quote quote)
                    (print (eval (car xvalp)))))))
            (set (quote xvalp) (cdr xvalp))
            (go loop))))
```

```lisp
(editf
   (lambda (x) (prog2
      (putd x (edite (getd x)))
      x)))

(editv
   (lambda (x) (prog2
      (set x (edite (eval x)))
      x)))

(editp
   (lambda (x) (prog2
      (rplacd x (edite (cdr x)))
      x)))

(edite
   (lambda (x) (prog (l y c)
            (typein t)
            (setq l (list
               x))
            (print (quote edit))
      a     (cond
               ((null (ersetq (setq c (read)))) (go a))
               ((null c) (return (car (lastr l))))
               ((numberp c) (edit1f c))
               ((eq c (quote copy)) (setq y (copy l)))
               ((eq c (quote restore)) (setq l (cond
                  (y y)
                  (t l))))
               ((eq c (quote p)) (edit3f (quote (p 0))))
               ((atom c) (print qmark))
               ((numberp (car c)) (edit2f c))
               (t (edit3f c)))
            (go a)))))

(edit1f
   (lambda (c) (cond
      ((eq c 0) (cond
         ((null (cdr l)) (print qmark))
         (t (setq l (cdr l)))))
      ((greaterp c 0) (cond
         ((greaterp c (length (car l))) (print qmark))
         (t (setq l (cons (car (nth (car l) c)) l)))))
      (t (print qmark)))))
```

```
(edit2f
    (lambda (c) (cond
        ((greaterp (car c) 0) (cond
            ((greaterp (car c) (length (car 1))) (print qmark
))
            (t (rplaca 1 (edit2af (sub1 (car c)) (car 1) (cdr
 c) nil)))))
        ((or
            (eq (car c) 0)
            (null (cdr c))
            (greaterp (minus (car c)) (length (car 1)))) (print
 qmark))
            (t (rplaca 1 (edit2af (sub1 (minus (car c))) (car 1)
 (cdr c) t))))))

(edit2af
    (lambda (n x r d) (prog2
        (cond
            ((null (eq n 0)) (rplacd (nth x n) (nconc r (cond
                (d (cdr (nth x n)))
                (t (cddr (nth x n)))))))
            (d (attach (car r) x))
            (r (rplaca x (car r)))
            ((rplaca x (cadr x)) (rplacd x (cddr x))))
        x)`)

(edit3f
    (lambda (x) (cond
        ((eq (car x) (quote 1)) (edit2f (list
            (cadr x)
            (eval (caddr x)))))
        ((eq (car x) (quote e)) (ersetq (print (eval (cadr x
)))))
        ((eq (car x) (quote n)) (nconc (car 1) (cdr x)))
        ((eq (car x) (quote p)) (bpnt (cdr x)))
        ((member (car x) (quote (ri ro li lo))) (errorset (nconc
 x (quote ((car 1)))) t))
        (t (print qmark)))))
```

```
(bpnt
    (lambda (x) (prog (y n)
                (cond
                    ((zerop (car x)) (setq y (car l)))
                    ((greaterp (car x) (length (car l))) (go b1
))
                    ((minusp (car x)) (go b1))
                    (t (setq y (car (nth (car l) (car x)))))))
                (cond
                    ((null (cdr x)) (setq n 2))
                    ((null (numberp (cadr x))) (go b1))
                    ((minusp (cadr x)) (go b1))
                    (t (setq n (cadr x))))
                (return (cond
                    ((nlsetq (print (leveln y n))) nil)
                    (t (print (quote edit)))))
        b1      (return (print qmark)))))

(leveln
    (lambda (x n) (cond
        ((atom x) x)
        ((zerop n) (quote ∧))
        (t (mapcar x (quote (lambda (x) (leveln x (sub1 n)))
))))))

(nth
    (lambda (x n) (cond
        ((atom x) nil)
        ((greaterp n 1) (nth (cdr x) (sub1 n)))
        (t x))))

(lastr
    (lambda (x) (cond
        ((null x) (error (quote (null list))))
        ((null (cdr x)) x)
        (t (lastr (cdr x))))))
```

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```
(r1
    (lambda (m n x) (prog (a b)
            (setq a (nth x m))
            (setq b (nth (car a) n))
            (cond
                ((or
                    (null a)
                    (null b)) (return (print qmark))))
            (rplacd a (nconc (cdr b) (cdr a)))
            (rplacd b nil))))

(ro
    (lambda (n x) (prog (a)
            (setq a (nth x n))
            (cond
                ((or
                    (null a)
                    (atom (car a))) (return (print qmark))))
            (rplacd (lastr (car a)) (cdr a))
            (rplacd a nil))))

(li
    (lambda (n x) (prog (a)
            (setq a (nth x n))
            (cond
                ((null a) (return (print qmark))))
            (rplaca a (cons (car a) (cdr a)))
            (rplacd a nil))))

(lo
    (lambda (n x) (prog (a)
            (setq a (nth x n))
            (cond
                ((or
                    (null a)
                    (atom (car a))) (return (print qmark))))
            (rplacd a (cdar a))
            (rplaca a (caar a)))))
```

APPENDIX A

OPERATING THE BBN-LISP SYSTEM

APPENDIX A.1

LISP LOADER

The LISP loader allows one to load several drum fields from
either paper tape or magnetic tape. In addition, there is
provision for transferring a system from drum to mag tape.
A complete system is treated as a file on tape (each core load
is one block of the file) and all tape commands are in terms
of files rather than blocks. Teletype should be connected
to channel 0 of the 630 scanner.

Instructions for Loading System Programs onto the Drum

The LISP loader can be used for setting up the drum fields of
the system programs, including itself. To do this:

    1.   Read into core 1 the system program to be placed
on a drum field.

    2.   Read into core 1 the program at location 0 for
that drum field.

    3.   Read into core 0 the LISP loader.

    4.   Type: nd
where n is the octal number of the drum field onto
which to dump core 1.

Instructions for Loading LISP with the Loader

    1.   Load mag tape of system on tape drive and set it
to automatic on unit 1.

2. Read into core 0 the paper tape of the LISP loader.
The mag tape will be rewound and the LISP loader will be
waiting for typein. (The LISP loader starts at 300.)

3. Type: nr
where n is the octal number of the file to be read in.
26 drum fields will be read off of the mag tape onto
the drum and the typewriter will type out n < m where n
is the first block number read (starting with 0) and m
is the last +1 block number read.

4. Type: 1
This will take the user to LISP.

Instructions for Writing LISP onto Mag Tape with the Loader

1. From LISP call the drum field with the LISP loader,
FIELD (25Q), or read into core 0 the paper tape of the
LISP loader.

2. Type: nw
where n is the octal number of the file that you wish
to write.

A.1-2

List of Commands Available in the LISP Loader (n is an octal number)

l	calls LISP
e	calls the editor on field 26
nr	reads onto the drum from mag tape file n
nw	writes current drum system on mag tape file n
nd	dumps core 1 onto relative drum field n
nc	reads relative drum field n into core 1
np	preserves core 0 on relative drum field n
ng	gets registers 0-177 on relative drum field n and transfers to 0
nu	selects the mag tape unit to be used. Starting the program at 300 automatically selects unit 1.
nb	sets the base field on the drum to n, i.e., drum loading will begin on field n from either core or mag tape. The base is initially set to 1. The first relative field n is 1, not 0. Relative field n is absolute field "n - 1 + base".
nf	sets the number of fields in a file. This value is initially set to 26 octal.
o	rewind (origin)
ns	space tape n files forward (or backward if n is negative). If n is zero the tape will be moved to the beginning of the current file. Spacing backwards has been known to cause trouble.

A.1-3

Error Printouts

n0f	tried to reference file 0 or drum field 0 (either absolute or relative)
fle	file error -- while searching for a designated file, a file longer than 64 blocks was encountered.
una	tape unit not available. If this is the first thing that happens it is because the program has attempted to rewind unit 1 and cannot for some reason.
pmc n	bad parity or missed character on reading or checking tape block n
nch	saw no characters for 6 inches
ept	saw tape end point
wcf n	write check failure mag tape block n
drf n	drum read fail, absolute field n
nem	no end mark has been entered
dwe	drum write error

APPENDIX A.2

USING LISP FROM THE COMPUTER ROOM TELETYPE

To use LISP from the computer room teletype: Connect the
teletype to channel 0 of the scanner and then load the LISP
system as described in Appendix A.1, LISP LOADER. The teletype
will carriage-return and be waiting for input into <u>evalquote</u>.

Manual restart should never be used as there are no known ways
to cause the system to halt or crash (if either does occur,
record all particulars and deliver to D. Murphy). The following,
however, do exist:

    start 202   reinitializes all sequence break
                                 routines and restarts

    start 203   reinitializes entire system, i.e.,
                                 kills everything and redefines only
                                 initial SUBR's and FSUBR's.

APPENDIX A.3

USING LISP FROM A REMOTE DATASET

To use LISP from a remote dataset: The LISP system should be loaded and running as described in Appendix A.1, LISP LOADER. Then:

Set the channel 0 dataset phone to "auto" (the channel 0 phone is the one on which the number 491-5120 appears).

From the remote dataset, push the "tel" button, and when the dial tone is heard in the attached receiver, dial 491-5120. The phone in the computer room will be answered automatically, and a tone will be transmitted. When this tone is heard, the "ORIG" button should be pressed, establishing the connection.

Special Codes for Control (see standard chart of teletype codes for complete set)

Octal Code	Character	Function
	rubout	deletes the line being typed in types out and deletes the last character typed in
	break key	causes an interrupt followed by an untrace. A second depression of this key halts the untrace.

Octal Code	Character	Function
204	control D	HANGUP, when transmitted by either computer or user, causes immediate hangup on both ends
207	control G	Bell
211	control I	Horizontal tab, on output only, causes carriage to be moved to next predefined tab stop
221	control Q	reader on: starts paper tape reader if tape is loaded
223	control S	reader off: when appearing on paper tape only, causes reader to stop after reading next character

APPENDIX B

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ARPA Order No. 627, dated 9 March 1965.	Hq. AFCRL, OAR (CRB) United States Air Force L.G. Hanscom Field, Bedford, Mass.

13. ABSTRACT

This report describes in detail the BBN-LISP system. This LISP system has a number of unique features; most notably, it has a small core memory, and utilizes a drum for storage of list structure. The paging techniques described here allow utilization of this large, but slow, drum memory with a surprisingly small time penalty. These techniques are applicable to the design of efficient list processing systems embedded in time-sharing systems using paging for memory allocation.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
LISP List Processing Language Paging Systems Drum Systems for List Structure List Structures Symbol Manipulation Language						

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